Influence of design on the microclimate in nest boxes exposed to direct sunshine

Murray V. Ellis

Science Section, NSW Office of Environment and Heritage,
PO Box 1967, Hurstville BC NSW 1481, Australia

ABSTRACT

Nest boxes have been widely used across the world to provide shelter for animal species, often to restore areas following the loss of natural tree hollows. While the microclimates of installed nest boxes have been studied, limited attention has been paid to whether microclimate is influenced by nest box size, shape and entrance dimensions. In this study the temperature and humidity patterns were recorded within six nest box designs that were exposed to direct sunshine. All were constructed of 19 mm plywood but varied in length by a factor of 2X, in volume by 3.5X and in entrance areas by 5X. All next boxes behaved the same thermally, closely following ambient during the night, but during the day they heated to 5 °C warmer than ambient by mid-afternoon. Fluctuations in humidity varied, with small nest boxes with large entrances being closer to ambient humidity than those with small entrances or large volumes. Overall, nest box size and shape had no detectable influence on the internal temperature fluctuations, but did to a slight extent on humidity patterns. Construction material and nest box placement are the likely drivers of the temperature and humidity patterns within nest boxes, and need to be the focus of efforts to keep nest boxes habitable when deployed, and designs should be selected on the basis of the target animal's preferences for size and shape.

Key words: artificial hollows; artificial tree cavities

DOI: http://dx.doi.org/10.7882/AZ.2016.007

Introduction

The loss of hollow-bearing trees through clearing, fires and silvicultural practices has led to the increasing use of nest boxes to manage resource bottlenecks for hollow-dependent fauna, mainly birds and mammals (e.g. Beyer and Goldingay 2006; Harley 2006; Goldingay *et al.* 2015). However, there are few data on what influences the effectiveness of such artificial hollows in wildlife management, although microclimate and box design are suspected of playing a role in nest box utilisation (e.g. Menkhorst 1984; Goldingay and Stevens 2009; Goldingay *et al.* 2015). These factors have been more extensively studied in relation to bird nesting success (e.g. Ardia *et al.* 2006; García-Navas *et al.* 2008; Butler *et al.* 2009; Charter *et al.* 2010) and there are also data relating to temperature and design influencing nest box use by mammals (e.g. Issac *et al.* 2008; Goldingay *et al.* 2015). The direct influence of size and shape on the thermal properties of nest boxes is difficult to extract from the literature as the boxes are installed in field situations with a variety of orientations and shading, construction material and exterior finishes (e.g. Goldingay 2015).

This study aimed to measure the influence of design on the diurnal cycle of the microclimate within nest boxes prior to installation on trees. There are a wide range of designs in use (e.g. Lindenmayer *et al.* 2003; Durant *et al.* 2009; Ball *et al.* 2011; Goldingay 2015), so following the extensive fires in Warrumbungle National Park in 2013 a variety of nest box designs were to be installed to provide artificial hollows for both birds and mammals. This provided the opportunity to investigate six of these designs to determine if there were differences in their internal temperature and humidity cycles.

Methods

The study was conducted in Warrumbungle National Park, New South Wales, Australia (31.304171 S, 149.015881 E) with measurements taken between the 26th and 30th of September 2014 inclusive. The study area consisted of a 100 m wide cleared valley floor with full exposure to the sun throughout the day and clear exposure to the night sky. Four of each of the six nest box designs constructed from 19 mm plywood (Table 1, Appendix) and varied in length by a factor of 2X, in volume by 3.5X and in entrance areas by 5X. They were installed in a grid at approximately 2 m spacing on an area of low grass and forbs in the centre of the valley floor. There is evidence of nest box colour influencing internal temperatures (Kerth *et al.* 2001; Lourenço and Palmeirim 2004; but see Goldingay 2015) so only nest boxes having a clear finish, allowing the pale colour of the timber to show, were used. They were installed on metal pickets so that their entrances faced south at approximately 1.5 m above the ground. This prevented direct sun penetration into the box interiors and directly warming the interior contents. A Stevenson screen was installed immediately south of the nest boxes to measure ambient conditions. Each box had a Thermochron iButton® (Maxim Integrated Products, Sunnyvale, California, USA) temperature logger with

Table 1. Size attributes of the six designs of nest boxes studied.

	Box				Opening		
Nest Box Type	Length (cm)	Width (cm)	Depth (cm)	Volume (l)	Type	Size (cm)	Area (cm^2)
1 Spout	26	25	30	15	spout	10 x 10	100
2 Large Parrot	25	25	100	52	spout	10 x 10	100
3 Small Parrot	20	25	46	18	round	6	28
4 Possum	25	25	43	22	round	8	50
5 Shrikethrush	26	25	30	15	rectangle	15 x 10	150
6 Glider	31	15	46	17	round	5	20

a 0.5 °C resolution placed on the nest box floor to record the temperature and relative humidity every 30 minutes. Two loggers were placed in the Stevenson screen and recorded the same measurements at the same time interval.

The maximum and minimum temperatures and humidities were extracted from the dataloggers for each of the 24 nest boxes and the means for each design were calculated. The mean temperature and humidity within each nest box design, and the difference compared to the ambient, were also calculated at 30 minute intervals across the five days of recording. Where there were variations between nest box designs analysis of variance was performed to determine its significance.

Results

The ambient temperatures ranged from 5.6 to 26.6 °C while the relative humidity ranged from 23.8 to 100%. The temperatures within all the nest boxes were very similar to one another across time and were consistently higher during the middle of the day than ambient, peaking between 13:00 and 15:00 each afternoon at approximately 5 °C above ambient (Figure 1, Table 2). The maximum temperatures within individual nest boxes ranged from 29.6 to 30.7 °C while the average maximum temperature (± s.e.) for each type of nest box ranged from 29.8 ± 0.1 to 30.3 ± 0.3 °C. The corresponding minimum values ranged from 4.6 to 5.5 °C and from 4.6 ± 0.1 to 5.3 ± 0.1 °C. These small ranges are at the limits of resolution of the temperature loggers used and so no difference could be detected.

Relative humidity patterns were more diverse. All nest boxes had humidities clustering near ambient during the middle of the day, but humidities were consistently lower than ambient during the night. The different nest box types varied in how much their humidities increased during the night, although all reached their peak at around dawn (Figure 2). In the first few hours after dawn the ambient humidity dropped rapidly, and for that period the humidity within the nest boxes was generally higher than ambient but also rapidly declining. The maximum humidities within individual nest boxes ranged from 83.4 to 99.5% while the average maximum humidity for each type of nest box ranged from 86.2 ± 4.3 to 99.2 ± 0.4%. The corresponding minima ranged from 26.7 to 36.9% and from 27.3 ± 0.3 to 35.5 ± 0.8%. ANOVA was performed on the arcsine transformed humidities and revealed significant differences between nest box designs for both the maximum ($F_{5,17} = 16.47$, $p << .001$) and minimum ($F_{5,17} = 27.28$, $p << .001$).

Time lags were evident in tracking changes in the ambient conditions for both nest box temperature and humidity. There were larger variation of humidities than temperatures,

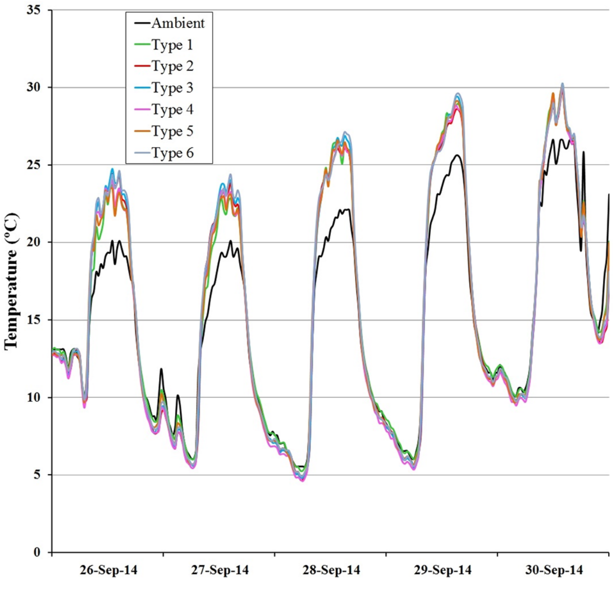


Figure 1. Temperatures within the six nest box designs compared to ambient over 5 days. Values for each day commence at 0030h and end at 2400h. Values are the mean of four replicate boxes.

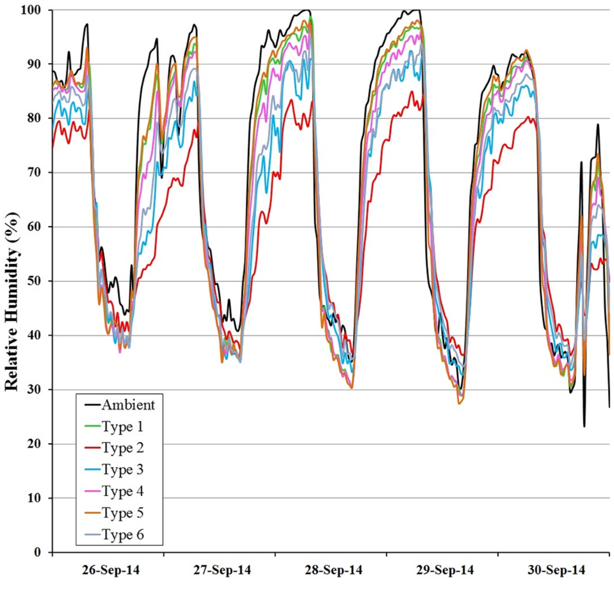


Figure 2. Relative humidity within the six nest box designs compared to ambient over 5 days. Values are the mean of four replicate boxes.

Table 2. The mean maximum and minimum temperature and humidity differences between the six nest box designs and the ambient conditions.

	Max Δ temp		Min Δ temp		Max Δ humid		Min Δ humid	
Nest Box Type	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1 Spout	5.23	0.16	-3.21	0.07	23.98	0.71	-15.00	0.87
2 Large Parrot	5.04	0.21	-5.90	0.10	23.47	0.58	-39.23	0.84
3 Small parrot	5.28	0.16	-5.23	0.13	25.90	0.70	-33.36	1.80
4 Possum	4.88	0.24	-4.63	0.13	22.40	1.37	-20.93	1.67
5 Shrikethrush	5.00	0.20	-3.44	0.15	18.20	1.43	-13.40	1.41
6 Glider	5.34	0.22	-4.98	0.30	24.31	1.01	-28.79	2.45

particularly during the early part of each night (Figure 2) as ambient temperatures dropped and humidity rose. The internal and ambient temperature and humidity of each type of nest box reflect this pattern. The maximum humidity difference (when the humidity in a box is at its highest compared to ambient) occurred between 07:30 and 09:00 each day and the period of high positive values was restricted to about two hours each morning. The minimum humidity difference (when the humidity in a box is at its lowest below ambient) occurred between 18:30 and 21:00 each evening and the period of high negative values was spread across much of the night, and is particularly evident for type 2 boxes (Table 2, Figure 2).

The variation in the difference between ambient and nest box humidity was related to the depth and volume of the nest box, with the larger nest boxes having comparatively lower humidities than shallower nestboxes each night (Figure 3, 4 & 5). The size of the entrance hole appears to have an influence, and nest boxes with smaller entrances had lower night-time humidities than similar size ones with larger entrances (Figure 3, 4 & 5).

Discussion

In this study nest box design had no detectable influence on the temperature regime experienced within the boxes. The temperatures within nest boxes tracked ambient across the night, and during the afternoon they rose to about 5 °C above the ambient which was in the twenties (Figure 1). This pattern is also reported for nest boxes in cold regions although with only a small rise of less than one degree above the average ambient maximum of about 6 °C (Grüebler *et al.* 2014). A simple explanation for this

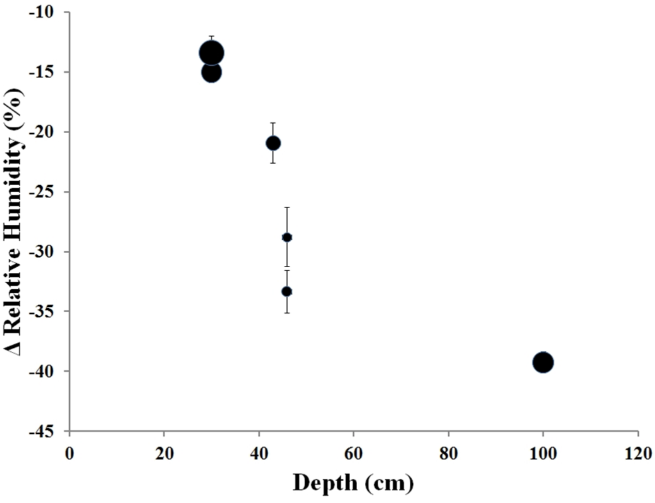


Figure 3. The maximum suppression of nest box relative humidity compared to ambient conditions (mean ± s.e.) in relation to the depth of each type of nest box (X axis) and the size of the entrance hole, represented by the size of the symbol.

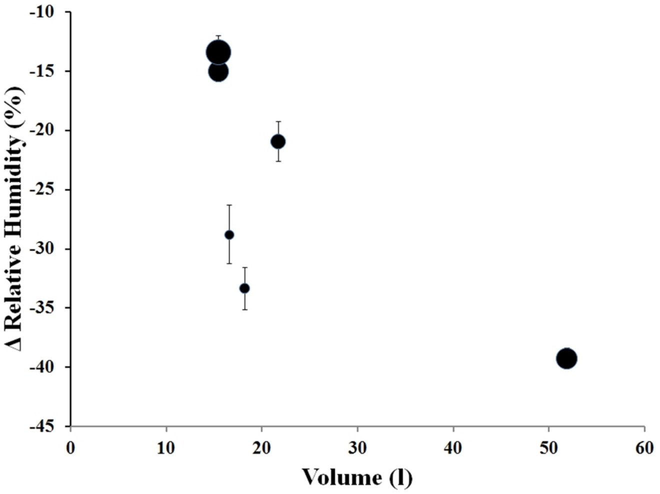


Figure 4. The maximum suppression of nest box relative humidity compared to ambient conditions (mean ± s.e.) in relation to the depth of each type of nest box (X axis) and the size of the entrance hole, represented by the size of the symbol.

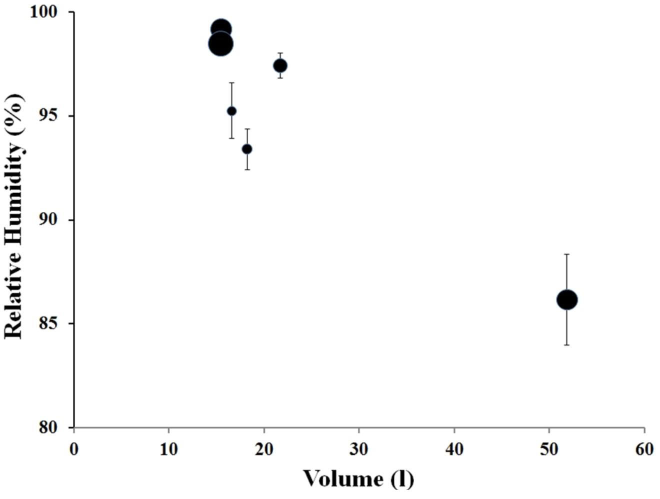


Figure 5. The maximum humidity levels (mean ± s.e.) in relation to the volume of each type of nest box (X axis) and the size of the entrance hole, represented by the size of the symbol.

is that all the boxes were experiencing the same heat flux. During each diurnal period part of the solar heat load on the sections of the nest box exposed to the sun would be absorbed and conducted to the internal airspace, and part radiated away from the outside of the nest box. As the internal temperature rises above ambient, heat would be absorbed by and then radiated away from the shaded side of the nest box. Even though the area exposed to the sun varied between the designs, there would be a corresponding shaded area and this balance seems to mean that the heat flux through all the designs was similar. There may be some internal convective heat movement, with the maximum temperature at the top of nest boxes studied by Goldingay (2015) being higher than the bottom, and consequently the potential loss of heat through the entrance hole via air movement, but such differences, if they existed, were not reflected in the temperatures at the bottom of the boxes.

Since temperature influences the relative humidity of an air mass even when there is no change in the absolute humidity, any temperature variations between nest box designs could have driven relative humidity differences. However, since the thermal performance of all the nest boxes was very similar, the differences in humidity (Figure 2) must be driven by the designs. Some moisture may have been absorbed and released by the nest box walls, but the influence of entrance size and box volume on humidity differences (Figures 3, 4 & 5) indicates that air exchange through the entrance is likely to drive much of the moisture transfer while the box volume and depth influence the humidity changes at the bottom of the box. This indicates that the thermal mass of the nest boxes must have had a strong buffering effect to maintain such similar temperatures across all the designs when there was such variation in air exchange, probably because the specific heat capacity of the construction material is much higher than that of the air within a nest box.

These relationships will alter once animals make use of the nest boxes for several reasons. Firstly, both birds and mammals will release metabolic heat into the nest box which will contribute to raising the temperature. The amount of increase will depend on the rate that the nest box dissipates heat, which will depend on the temperature difference to the surrounding environment and the rate that heat is conducted through the wall of the nest box and radiated away. Secondly, many animals will add bedding to the nest boxes which will alter the airflow and the insulating properties. Changing the airflow should impact on the humidity pattern within the nest boxes, but may also introduce a mass that has some buffering impacts through absorption and release of moisture as the relative humidity changes. Thirdly, the presence of animals within a nest box would release moisture through their breathing which should raise the relative humidity, particularly for the period when the animals are inside the nest box.

Goldingay *et al.* (2015) demonstrate that different species can show preferences for different designs of nest box, and recommends the use of specific designs for habitat restoration for different species. My results suggest that the creation of specialised nest box designs, by varying the volume and entrance size, should have minimal impacts on the thermal performance, but there may be implications if specific humidity ranges are needed.

My results demonstrate that, when not subjected to a direct solar heat load, the nest box designs all closely tracked ambient temperatures with a slight time lag. This means that managers should be able to influence the temperatures within nest boxes by manipulating heat loads during sunlight periods. Placement of nest boxes relative to tree foliage and trunks is the simplest way to shade them from direct solar heat loads. Additionally, installing shading structures, coating the exposed sides with heat reflecting materials (e.g. heat reflective paints, Pockett and Belusko (2010)), or insulating the side exposed to the sun to reduce the rate of heat conductance into the nest boxes, should lower the maximum temperatures attained. Conversely, insulating the shaded side of the nest boxes should reduce the rate of heat loss through that side and raise the maximum temperatures attained, which may be of benefit if the nest boxes are being used in a cool climate but may not be sufficient to overcome the ambient temperature tracking of nest boxes in cold climates (e.g. Grüebler *et al.* 2014). What will be critical is determining what time of year the nest box will be used. The values obtained in this study during spring are directly relevant to the nest boxes that are used by birds for nesting at that time of year. However, nocturnal birds and mammals could use these boxes at any time of year so what happens during seasonal extremes when the difference between conditions within the boxes and ambient may be at their maximum needs further investigation.

Additionally, since the temperature patterns shown in this study seemed to be driven by the absorption and conductance of heat through the wall materials rather than by air flow, internal nest box temperatures should be able to be buffered by the use of thermal mass. The simplest form would be the addition of thermal mass inside the nest box to dampen the fluctuations in temperature. A more complicated option would be to use the tree that the nest box is attached to as a thermal buffer. Koalas are known to use live tree trunks as heat sinks during hot days, when trunk surface temperatures were up to 8 °C cooler than ambient, by pressing their bodies against cooler sections of trees (Briscoe *et al.* 2014). A nest box that is in close thermal contact with its supporting tree should similarly be able to dissipate heat into the tree trunk on hot days. However, studies on large buildings show that there are complex interactions between thermal mass, heat conductance and insulation location on the temperature moderation within buildings (see overview by Roach *et al.* 2010) and these factors need to be explored at smaller scales if they are to be used to improve nest box thermal properties.

Conclusion

Nest box size, shape and entrance dimensions had no influence on the thermal fluctuations in these nest box designs so wildlife managers should be free to focus their efforts on selecting designs that are preferred by their target species. However, if humidity management is important then changing entrance size and box volume needs to be explored. Where maintaining nest boxes within desired temperature ranges is required, this can be achieved by management of the heat loads (e.g. placement of the nest box relative to direct sun, the use of absorbing or reflecting external finishes), the conductive properties of the nest walls and the thermal mass of the nest box, rather than size and shape of the nest box *per se*. Further studies should be done to test these proposals and particularly at the height of summer and in the depth of winter with occupied boxes.

Acknowledgements

This work was carried out with the consent of Mark Fosdyck, the assistance of Karen Hudson and Sue Brookhouse, and the cooperation of the other staff of Warrumbungle National Park. Susan Rhind provided critical comments on the draft of this manuscript.

References

Ardia, D. R., Perez, J. H. and Clotfelter, E. D. 2006. Nest box orientation affects internal temperature and nest site selection by tree swallows. *Journal of Field Ornithology* 77: 339-344. http://dx.doi.org/10.1111/j.1557-9263.2006.00064.x

Ball, T., Goldingay, R. L. and Wake, J. 2011. Den trees, hollow-bearing trees and nest boxes: management of squirrel glider (*Petaurus norfolcencis*) nest sites in tropical Australian woodland. *Australian Mammalogy* **33:** 106-116. 10.1071/AM10050

Beyer, G. L. and Goldingay, R. L. 2006. The value of nest boxes in the research and management of Australian hollow-using arboreal marsupials. *Wildlife Research* 33: 161-174. 10.1071/WR04109

Briscoe, N.J., Handasyde, K.A., Griffiths, S.R., Porter, W.P., Krockenberger, A. and Kearney, M.R. 2014. Tree-hugging koalas demonstrate a novel thermoregulatory mechanism for arboreal mammals. *Biology Letters* **10**: 20140235. http://dx.doi.org/10.1098/rsbl.2014.0235

Butler, M. W., Whitman, B. A. and Dufty, A. M. 2009. Nest box temperature and hatching success of American kestrels varies with nest box orientation. *The Wilson Journal of Ornithology* **121:** 778-782. http://dx.doi.org/10.1676/08-124.1

Charter, M., Meyrom, K., Leshem, Y., Aviel, S., Izhaki, I. and Motro, Y. 2010. Does nest box location and orientation affect occupation rate and breeding success of barn owls *Tyto alba* in a semi-arid environment? *Acta Ornithologica* **45:** 115-119. http://dx.doi.org/10.3161/0001645 10X516164

Durant, R., Luck, G. W. and Matthews, A. 2009. Nest-box use by arboreal mammals in a peri-urban landscape. *Wildlife Research* **36:** 565-573. doi:10.1071/WR09058

García-Navas, V., Arroyo, L., Sanz, J. J. and Díaz, M. 2008. Effect of nestbox type on the occupancy and the breeding biology of tree sparrow *Passer montanus* in central Spain. *The Ibis* **150:** 356-364. http://dx.doi.org/10.1111/j.1474-919X.2008.00799.x

Goldingay, R. L. 2015. Temperature variation in nest boxes in eastern Australia. *Australian Mammalogy* **37:** 225-233. http://dx.doi.org/10.1071/AM14040

Goldingay, R. L., Rueegger, N. N., Grimson, M. J. and Taylor, B. D. 2015. Specific nest box designs can improve habitat restoration for cavity dependent arboreal mammals. *Restoration Ecology* **23:** 482-490. http://dx.doi.org/10.1111/rec.12208

Goldingay, R. L. and Stevens, J. L. 2009. Use of artificial tree hollows by Australian birds and bats. *Wildlife Research* **36:** 81-97. http://dx.doi.org/10.1071/WR08064

Grüebler, M. U., Widmer, S., Korner-Nievergelt, F. and Naef-Daenzer, B. 2014. Temperature characteristics of winter roost-sites for birds and mammals: tree cavities and anthropogenic alternatives. *International Journal of Biometeorology* **58:** 629-637. http://dx.doi.org/10.1007/s00484-013-0643-1

Harley, D. K. P. 2006. A role for nest boxes in the conservation of Leadbeater's possum (*Gymnobelideus leadbeateri*). *Wildlife Research* **33:** 385-395. http://dx.doi.org/10.1071/WR04038

Isaac, J. L., Parsons, M. and Goodman, B.A. 2008. How hot do nest boxes get in the tropics? A study of nest boxes for the endangered mahogany glider. *Wildlife Research* **35:** 441-445. http://dx.doi.org/10.1071/WR08016

Kerth, G., Weissmann, K. and König, B. 2001. Dayroost selection in female Bechstein's bats (*Myotis bechsteinii*): a field experiment to determine the influence of roost temperature. *Oecologia* **126:** 1-9. http://dx.doi.org/10.1007/s004420000489

Lindenmayer, D. B., MacGregor, C. I., Cunningham, R. B., Incoll, R. D., Crane, M., Rawlins, D. and Michael, D. R. 2003. The use of nest boxes by arboreal marsupials in the forests of the central highlands of Victoria. *Wildlife Research* **30:** 259-264. http://dx.doi.org/10.1071/WR02047

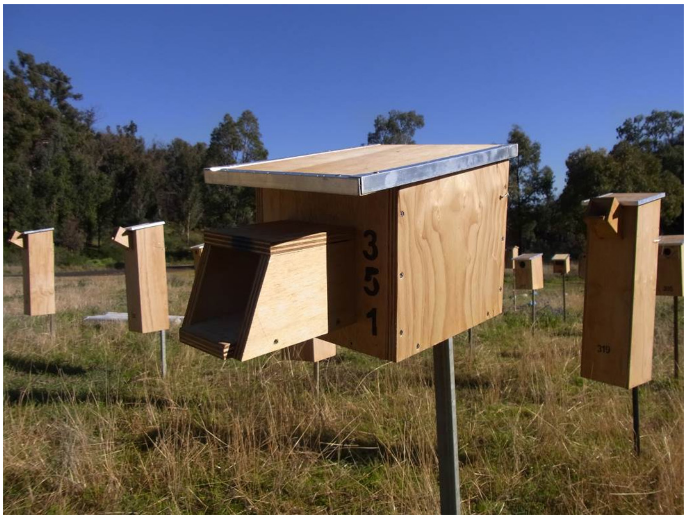
Lourenço, S. I. and Palmeirim, J. M. 2004. Influence of temperature in roost selection by *Pipistrellus pygmaeus* (Chiroptera): relevance for the design of bat boxes. *Biological Conservation* **119:** 237-243. http://dx.doi.org/10.1016/j.biocon.2003.11.006

Menkhorst, P. W. 1984. Use of nest boxes by forest vertebrates in Gippsland: acceptance, preference and demand. *Australian Wildlife Research* **11:** 255-264. http://dx.doi.org/10.1071/WR9840255

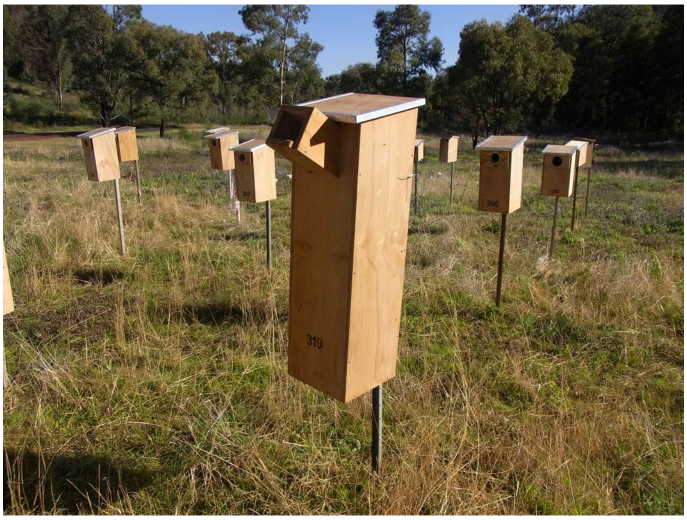
Pockett, J. and Belusko, M. 2010. A Review of Heat-reflective Paints. *In* Proceedings of the Solar2010, the 48th AuSES Annual Conference. Canberra, Australia.

Roach , F., Bruno, M. and Belusko, M. 2010. Towards an understanding of the use of thermal mass in the cooling of commercial buildings. *In* Proceedings of the Solar2010, the 48th AuSES Annual Conference. Canberra, Australia.

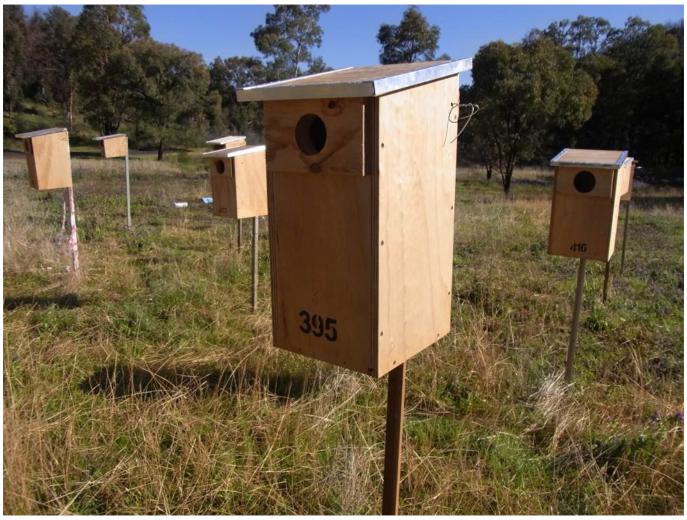
APPENDIX 1



1 Spout

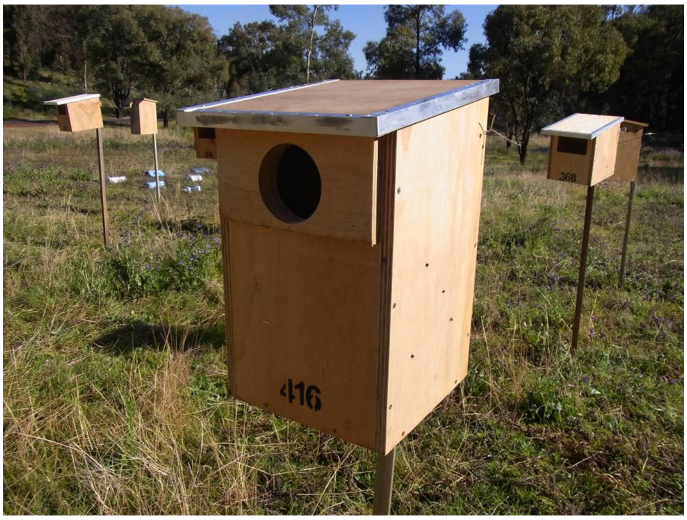


2 Large Parrot

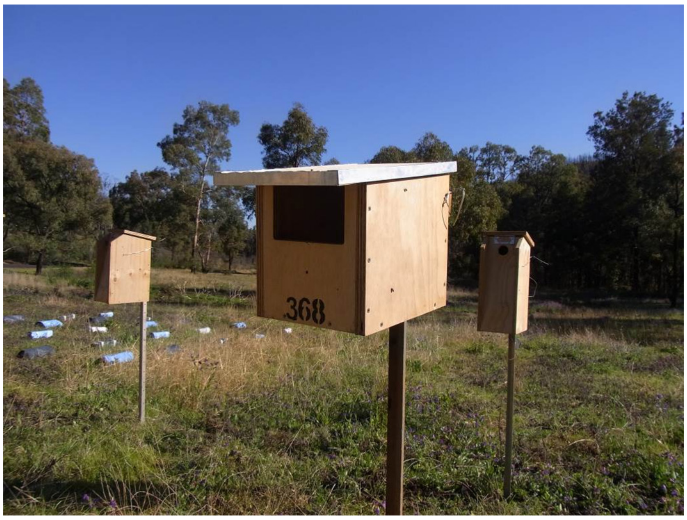


3 Small Parrot

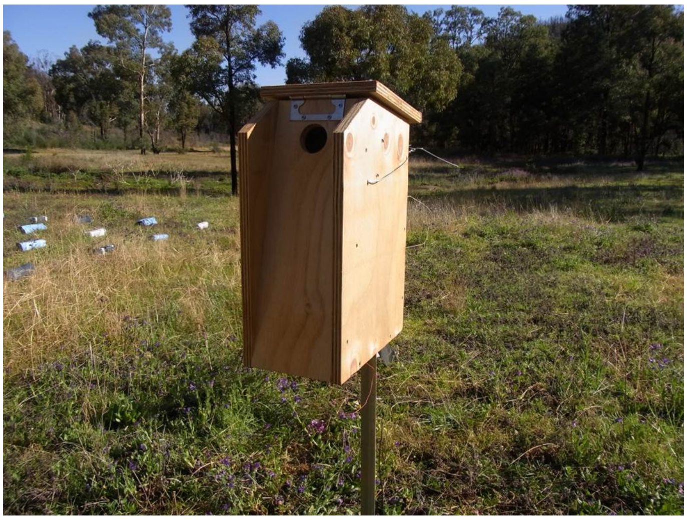
APPENDIX I



4 Possum



5 Shrikethrush



6 Glider